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ABSTRACT

This monograph addresses concerns about mathematics and science instruction and educational outcomes for Native students. The sociocultural contexts of schooling and community come together in particular ways to influence how Native children learn and, consequently, their life outcomes. It is important to look beyond the performance of individual students to the systems in which they are educated and to the historical and social influences on how mathematics and science are conceptualized and taught. Methods for implementing current mathematics and science reforms are shaped by assumptions about what children should know and be able to do. This monograph seeks to make such assumptions and the Western cultural values underlying them more explicit, and suggests that a generic approach to reform is ineffective and inequitable. Student differences with implications for teachers' choices about instructional strategies include differences in: (1) ways of knowing with regard to mathematics and science, rooted in varying world views; (2) approaches to learning and problem solving; (3) communication styles, strategies, and uses; and (4) cultural values about use and sharing of particular kinds of knowledge. Ethnoscience and ethnomathematics (forms embedded in cultural activities, the workplace, or everyday life) can serve to contextualize instruction--to provide real-life connections that make classroom theories and practices meaningful. Several examples demonstrate how such connections can be made. A set of guidelines is presented for instruction that bridges cultures and situates mathematics and science learning in meaningful contexts for Native students, as well as for all underserved students. Contains 130 references. (SV)

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Culturally Responsive Mathematics and Science Education for Native Students

The Native Education Initiative of the Regional Educational Laboratories

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Culturally Responsive Mathematics and Science Education for Native Students

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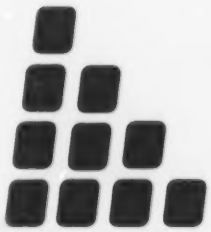

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Culturally Responsive Mathematics and Science Education for Native Students

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Introduction

Often, writings addressed to teachers go directly to remedies or classroom activities rather than lay a foundation that puts recommendations in a meaningful framework. Research papers, on the other hand, typically make no effort to envision bridges to practice — and that is not their purpose. Here, we hope to give readers enough background information and theoretical perspective to evaluate our recommendations for practice, bringing to bear their own knowledge and experience within their own communities — school and beyond.

In this monograph, we have attempted to address concerns about mathematics and science instruction and educational outcomes for Native* students. The sociocultural contexts of schooling and of Native communities come together in particular ways that influence how children learn and consequently influence "life outcomes" for Native students. Therefore, we believe it is important to look beyond the performance of individual students to the systems in which they are educated (in schools and communities), the historical and social systems that have shaped the form schooling takes, and particular influences on how mathematics and the sciences are conceptualized and taught.

Mathematics and science reforms are taking place in a social and political context, with many assumptions made that need to be examined. The standards and methodologies for achieving them are situated in particular points of view about what is valuable for children to know and be able to do. We suggest that the values underlying these standards and methodologies need to be made more explicit and that wider participation in determining them would ultimately be beneficial to all students.

We have chosen to address pedagogical concerns related to both mathematics and science, although there are strong practical and theoretical reasons to treat the two disciplines separately. Of course each constitutes a vast and diverse domain in itself, and generalizations about either are risky. In addition, approaches to science instruction have traditionally differed from approaches to mathematics instruction, with the former tending more toward the empirical and inductive and the latter more toward the theoretical and deductive. Nevertheless, we have elected to discuss mathematics and science within the same paper for the following reasons:

**A note regarding terminology: In this monograph the term "Native" is often used to refer to American Indian (or Native American) and Alaska Native peoples, and at times to indigenous peoples of Canada. We recognize that these cultural and ethnic groups are distinct, yet they do share many common values and practices. Furthermore, students from all of these groups do, on the whole, share similar experiences in schools today; and our concerns about appropriate mathematics and science education extend to all of them.*

- Both mathematics and science instruction have not been successful, overall, with Native students — probably for the same reasons.

- Proposed instructional solutions in the two domains have a common denominator.

- Mathematics and science skills often go together in the workplace; in particular, success in occupations in science and technology depends on proficiency with some kinds of mathematics.

- The two domains are linked in the public's mind and thus in the public debate about educational reform.

The Context: National Reforms in Mathematics and Science Education

Numerous studies have documented the poor achievement levels of many American students in mathematics and science (International Association for the Evaluation of Educational Achievement, 1988). Although some students do extremely well, as others move through the nation's elementary and secondary schools, large numbers of them rapidly lose interest in mathematics, science and technology, perform progressively worse on tests, and show disturbingly little interest in pursuing careers that require proficiency in these crucial core subjects. This trend is particularly pronounced among ethnic and racial minorities and females — groups that are currently underrepresented in such career fields and yet constitute an increasing percentage of our student body and future workforce (cf., Cole & Griffin, 1987; The Task Force on Women, Minorities and the Handicapped in Science and Technology, 1988; Oakes, 1987; Oakes, 1989).

Educators and the public at large are concerned about low performance in mathematics and science, in part because they fear that the nation's future economic security depends upon technological superiority (a fear that may not be based in reality). Another spur to educational reform has to do with anticipated changes in the nature of work: as the American workforce continues to shrink, the need for workers is expanding. As a result, our society and economy will increasingly rely on an educated populace skilled in interpersonal relations who can think expertly in an integrated, interdisciplinary, intuitive and flexible way to solve complex problems (Perry, 1994; Zarinnia & Romberg, 1987). These ways of relating and thinking are, incidentally, more associated with women and non-dominant cultural groups, on the whole, than with dominant culture men. For this reason, the disproportionate loss of student participation from these groups is doubly troublesome. Furthermore, critical thinking about practices in the marketplace, about challenging political circumstances, and about social issues requires a level of literacy in several disciplines — mathematics and science included — that is not routinely achieved by a majority of students. We believe that there are alternative pedagogical approaches that could both support improved performance among underserved groups and result in an educated populace capable of the kind of integrated, critical thinking alluded to above.

We want to delve below the surface of the educational, social, economic and political issues mentioned and highlight what we believe to be their relationships to and implications for underserved students. While our examples will center largely around Native students, our concerns extend to all students who have not had access to adequate education in mathematics, science, and technology. To penetrate beyond the rhetoric, we must examine some assumptions about education and schooling. One of the most fundamental assumptions that needs to be questioned has to do with the relationship between education and the economy. We address it at the very outset, because so many educational decisions are currently based on or rationalized by it.

The economic problems of the United States are not the fault of the schools, despite the claims or inferences of many business and government leaders. In fact, there are at present too many college-educated workers for the available jobs requiring a college degree (Bracey, 1994). As reported in Rotberg (1994), a wide-scale study of U.S. businesses conducted by a management consulting firm concluded that there was no shortage of skilled workers. Rather, "shifting technologies, restructured industries, and poor managerial judgments" (Cuban, 1994, p. 44) are the true culprits, along with governmental policies that affect exchange rates, wages, licensing agreements, and the like (Rotberg, 1994) — elements over which public education has little authority.

Based on the information presented above, we would argue that there are two important conclusions: 1) we need to change *the way* in which we educate students, and 2) inequities in access to appropriate, high-quality education are egregious and must be addressed. The United States has a highly educated and productive workforce, but it also has an extremely inequitable public education system that consistently provides opportunities to some children that it does not provide to others. Discrepancies in resources (both financial and human) between wealthy and poor schools are quite shocking: within the same state, affluent districts often spend two to three times as much per student as do poor districts (Rotberg, 1994). And, despite claims to the contrary, achievement outcomes of students are most certainly related to the amount of money spent to educate them (Hedges, Laine, & Greenwald, 1994). It is not difficult to conclude that even though the economic security of the country may not be at immediate risk, it is likely that our future as a democracy is.

Democracy is threatened when some groups are systematically denied access to an education that enables both life choices and informed participation in public debate about complex social, environmental and political issues. Many of our decisions as responsible citizens demand understanding of mathematical and scientific concepts, yet many students do not achieve even rudimentary competence in mathematics and science. Because of the widening gap between rich and poor, we are in grave danger of becoming a two-tiered society composed of a wealthy, technologically adept elite and a poor, underemployed, scientifically illiterate underclass. And whether the health of the *overall economy* depends on improved education of individuals or not, the economic security of *individuals* is intimately related to their level of education. People who are more educated make more money. In our view, equitable solutions to the problems we pose need to address parallel goals for students of a) economic security, b) freedom and ability to make informed choices about career paths, and c) the ability to fulfill their own particular life aims within their own communities and beyond. We join Fasheh (1991) in endorsing a more lofty aim for education as well: "to release the human capacity to understand and act in order to transform consciousness and society" (p. 60).

New Standards for Students

Reflecting a widespread belief in the importance of addressing concerns about mathematics and science in particular, one of the eight national education goals in Goals 2000: The Educate America Act specifically calls for U.S. students to be first in the world in mathematics and science achievement by the year 2000 (America 2000, 1991; National Education Goals Panel, 1991; U.S. Department of Education, 1991). While agreeing with the goal of improving student outcomes, many Native educators (among others) find the nationalistic, competitive framing of this goal offensive. If the nation is to have any success in even beginning to address this goal, it will have to take a systemic approach rather than rely on piecemeal efforts to improve science and mathematics education. Systemic reform involves articulating high standards, embodying the resulting standards in curriculum frameworks, and using assessments linked to the standards and frameworks to monitor success and provide essential feedback to systems and individuals. The entire reform process should address the interests of all students. The feasibility of developing respected standards at a national level that states can use has been demonstrated in mathematics, although there are differences among states and districts in levels of ability, and in willingness to use the standards to guide educational practices. Standards set in 1989 by the National Council for Teachers of Mathematics (NCTM) now effectively serve as the nation's manifesto for change in mathematics education. Similar national standards are now being developed in science (National Committee on Science Education Standards and Assessment, 1994).

Reformed mathematics and science frameworks chart a course for curriculum reform and are consistent with thinking embodied in the National Council of Teachers of Mathematics Curriculum and Evaluation Standards for School Mathematics (NCTM, 1989) and the American Association for the Advancement of Science Project 2061 Report, Science for All Americans (AAAS, 1989), as well as in other documents (cf., California Department of Education, 1990; 1992). Grounded in a constructivist theory of learning, the new mathematics standards and frameworks focus on encouraging students to explore mathematical concepts related to their everyday experiences (Mathematical Sciences Education Board, 1989; 1990; 1991) and to complex social issues and environmental problems.

The National Council of Teachers of Mathematics has acknowledged concerns about disparities between affluent and poor districts in their ability to provide a high-powered curriculum that includes technology and sophisticated materials. However, "[i]t requires little cynicism to predict that, unless proactive steps are taken to ensure that diverse learners are included in the current mathematics education reform movement, the next wave of educational reform will bemoan, as this one so eloquently does, the low achievement of precisely those students who are in most danger of being omitted from today's reforms" (Secada, 1991, p. 315).

Similarly, new science frameworks define science understanding in terms of concepts rather than minute skills or knowledge of facts and formulas, and stress an active learning role for each student (Bybee, Buckwald, Crissman, Hell, Kuerbis, Matsumoto, & McInerney, 1989; Oakes, 1990; Commission on Life Sciences, 1990; Loucks-Horsley, Kapitan, Carlson, Kuerbis, Clark, Melle, Sachse, & Walton, 1990). They emphasize high standards for all students, interdisciplinary thematic teaching, active, hands-on exploratory learning, integration of key concepts rather than memorization of a mass of isolated facts, the teaching of science process skills, assessment aligned with the framework pedagogy, and integration of science with technology and social issues. All of these interconnected elements of instructional reform will require teachers to upgrade their skills significantly — particularly if teachers are to succeed with currently unreached students. Thus, in addition to structural and curricular remedies, there is a need to focus on teachers and what they need to know in order to teach effectively. Major concomitant reforms in the provision of professional development for teachers are thus necessary as well.

A Standard of Equity for the Reform Agenda

Ultimately, the success of any reform effort in our schools must be measured by the degree to which it is able to effect meaningful change in the educational lives of underserved students, whose problems in, and with, our schools have been a major catalyst for seeking reform in the first place. And, equally important, we should not imagine that we can effect such change without access to the perspectives of people who live and work in the diverse cultural communities from which these students come. Including differing perspectives means that we would turn on its head the strategy of putting reforms in place for the "majority" and then adapting them for "minorities." If we can show that the reforms are able to address the needs of "minority" students, then we have shown that they are worthwhile. Secada (1992) poses the following:

> If reform is to matter it must *begin* [emphasis added] with the populations for whom we have drawn these special categories. Curriculum and instruction should first be effective with these students, and then applied to other populations... [and] the notions of disadvantage and compensatory education that are linked to these populations should be replaced by notions that acknowledge their competence (p. 654).

Top-down reforms, such as those associated with Goals 2000, have not confronted the needs of "non-mainstream" students head-on and up-front; nor have they reflected a broad-based inclusion across diverse communities. In fact, they are particularly vulnerable to charges of ignoring the pluralism of society and of reducing the intellectual freedom necessary to allow for local input into curricula and instruction (Arons, 1994).

New Standards for Teachers

Largely as a result of recommendations contained in the 1986 Carnegie report, A Nation Prepared: Teachers for the 21st Century, a National Board for Professional Teaching Standards was established (Carnegie Task Force on Teaching as a Profession, 1986). Central to the work of the National Board has been the creation of new and more rigorous standards for the teaching profession. The Board hopes that clear and definitive standards of excellence for assessing teacher knowledge and performance will also begin to inform the content of teacher education programs so that teachers emerge from these programs with the kinds of knowledge and experiences necessary to make a real difference in the educational lives of students. But what are the standards of excellence for teachers that are likely to improve mathematics and science education? And, in particular, what are the standards that will improve mathematics and science achievement for the large and growing population of underserved students in our schools?

Those who see higher standards for teachers as the key to meaningful educational reform hold that there is a "knowledge base" that underlies and explains effective teaching, and that it is possible to specify what that knowledge base is — in other words, what it is a teacher needs to know in order to teach effectively. Some are uncomfortable with the term "knowledge base," suggesting that it implies a static or finite repertoire of information; but it can be thought of as dynamic knowledge that is reshaped through increasing professional experience. National Board President James Kelly makes it clear that this knowledge base extends beyond teachers' pedagogical and subject-matter knowledge to include "knowledge of education aims and objectives," "reasoning as a basis for decision making," "understanding of professional responsibility," and "*responsiveness to students and their individual differences*" (Carnegie Quarterly, 1989, p. 4 [emphasis added]).

In fact, a growing body of work suggests that this last-mentioned ability is one that is crucial to academic achievement for many underserved students, specifically the teacher's ability to fashion a curriculum that is more personal and more directly linked to students' cultural experiences (cf., Au, 1980; Barnhardt, 1982; Cazden, John & Hymes, 1972; Hollins, King & Hayman, 1994). Unfortunately much of the knowledge on culturally influenced notions of good teaching remains unrecorded and unformalized because, as a whole, educators (researchers and practitioners alike) have made little effort to elicit the perspectives and experiences, or study the classrooms, of teachers who are highly effective with non-mainstream students. Delpit (1995) argues that the perspectives of teachers of color in particular have been virtually ignored in the academic dialogue about what constitutes effective pedagogical practice, even when the dialogue has centered specifically on the educational needs of children of color.

This "silenced dialogue" between educators of color and members of the mainstream educational community described by Delpit only mirrors the lack of understanding and miscommunication that is enacted daily in class-

rooms across the country. From this perspective, the biggest challenge for those seeking meaningful educational reform lies not just in figuring out a methodology for better assessing what we already know, or assume we know, about effective teaching. Rather, it lies in exploiting the conditions of possibility such reforms present for broadening the knowledge base on culturally-responsive pedagogy. The reform process should offer an opportunity to expand the knowledge base to include the perspectives and experiences of teachers and researchers from a diverse range of cultural backgrounds. It is these people who can inform the field about the kinds of teacher behaviors and practices that work most effectively in non-mainstream settings.

Necessary Pedagogical Knowledge

It is not clear that proposed national standards in any of the content areas as they are currently written represent a deep enough understanding of the implications of linguistic, cultural, ethnic and racial diversity for American education. It *is* clear that current reforms are proceeding much in the way that reforms in education have always proceeded — with a presumption that what is good for the politically dominant group is good for all communities or that once in place, reforms can be modified to suit the needs of "different" children. A more specific form of this ideology is that "good teaching is good teaching." However, we know that this is not the case. If everything important about good teaching were generalizable across settings, a "good teacher" would be equally effective in any classroom. Rather, there is much about good teaching that is specific to a given cultural context and that is not easily transferable to another situation (cf., Bartolomé, 1994; Nelson-Barber & Meier, 1990; Reyes, 1992).

In fact, many teachers who are successful with learners from diverse backgrounds draw on their ability to convey subject matter within the context of familiar cultural experiences, local values, shared communicative norms and interactive styles (cf., Au, 1980; Delpit, 1988; Hollins, King & Hayman, 1994; McLaughlin & Tierney, 1993; Preston, 1991; Tharp 1989). For example, cooperative learning will not look the same in all settings; conditions for establishing trust between teacher and students necessarily entail understanding of particular cultural values; what counts as culturally-acceptable communication patterns that allow students to participate in classroom discussion is variable; linking students' personal experiences with learning activities requires appreciation for and understanding of those experiences. (cf., Lipka, 1991; Nelson-Barber, 1991; Philips, 1983; Swisher & Deyhle, 1987; U.S. Department of Education, 1994).

Many educators, including those who teach teachers, know little or nothing about the experiences and perspectives of teachers who live and work in diverse cultural communities. Even when presented with these experiences and perspectives, they often fail to lend them credence if they fall outside what they know to be "good" or "progressive" practice as defined in current educational literature. Certainly, many of the proposed reforms in mathematics and science instruction stand to benefit all students. However, the ways in which they are carried out in different communities will need to vary.

Our intent is to discuss many of the reasons that such a generic approach to reform is ineffective and inequitable. First we will discuss some of the student differences that have implications for teachers' choices about instructional approaches and strategies. These include 1) differences in ways of knowing with regard to mathematics and science — differences that are rooted in varying world views; 2) differences in approaches to learning and problem-solving; 3) differences in communication styles, strategies, and uses (including ways of demonstrating knowledge); and 4) differences in cultural values related to individuals' and groups' relationship to particular kinds of knowledge (e.g., who should know what, who should make public or share what knowledge). We will then turn to a brief examination of some of the often tacit beliefs held by Western educators that prevent them from understanding or appreciating alternative epistemologies and world views and ultimately from valuing their "minority" students' knowledge and abilities. We will explore in some depth assumptions about what constitutes mathematics and science and relations between ethnomathematics/ethnoscience and "academic" mathematics and science, with a view to understanding the roles played by both in students' learning.

Taking the stance that all knowledge and ways of knowing are culturally and historically situated, we will suggest what we consider to be a necessary contextualizing of the "preferred" approach to mathematics and science instruction — something that is missing from the proposed national standards. It is important to keep in mind that underlying the reform efforts are "beliefs and values about what it ought to mean to know and do mathematics [or science or social studies] in school. These beliefs and values are themselves open to challenge and criticism, thus bringing to the fore the moral and ethical aspects of educational research and theorizing" (Cobb, 1994, citing Nicholls, 1989). Finally, we will synthesize a set of guidelines for fostering a vision of instruction that bridges cultures, situates learning in meaningful contexts, and enables all students to become flexible users, interpreters, and creators of mathematical and scientific knowledge.

Throughout the paper we will use examples rooted in Native communities, because we want to highlight pedagogical and social issues within those underserved communities in particular. However, as we have suggested, the issues of equity and diversity we raise are germane to all underserved students. Before turning to a more detailed discussion of these complex issues, we present a broad overview of the demographic backdrop and the often unexamined assumptions and practices that challenge the implementation of equitable reform.

Challenges to a Standard of Equity

Demographics and Discrepancies

Members of so-called minority groups now account for 22 percent of the U.S. population. By 2015, the proportion is expected to increase to 33 percent (cf., Catteral & Cota-Robles, 1988). If current projections hold true, "minority" students will represent at least 40 percent of the public school population in this country by the middle of the next century. In California alone, more than half the students are now members of ethnic minorities (Guthrie, Kirst & Odden, 1990). According to 1990 Census Bureau data, the Native students in this California group constitute the second largest population of Native students in the country (U.S. Bureau of Census, 1990). Though today's ethnically diverse classrooms have the potential to offer contexts for rich schooling experiences, the overrepresentation of children of color in low-ability groups, in special education classes, and in the ranks of those who drop out of school underscores just the opposite outcome (cf., Murray & Jackson, 1982; Reschley, 1988; Rumberger, 1987).

These statistics are most bleak for Native students, who are twice as likely as White students to have more than two factors considered to place them at risk. They are more likely to live in single parent homes, have parents without a high school diploma, have limited English proficiency, and/or have a sibling who dropped out of high school (cf., U.S. Department of Education, 1994).

In mathematics, discrepancies in achievement based on ethnicity and race are evident virtually as soon as students are systematically tested. But the tests themselves are not neutral instruments. They are matched neither to the experiences nor the ways of learning and displaying knowledge of many students of color (cf., Estrin, 1993; Oakes, 1990). Noting the abundance of tests performed on Native students, as long ago as 1977, participants in an American Association for the Advancement of Science (AAAS) conference on mathematics in American Indian education expressed the following concerns:

> Indian students are largely tested for their deficiencies rather than for their proficiencies, and for their "deviance" in white cultural terms than for their "normalities" in Indian terms... Indian students are tested as "Indian," regardless of their background and distance from traditional cultural roles and lives. [Their needs are] more directly related to inadequate school preparation, for example, than to "Indianness" or federal school education. [Finally,] testing was aimed at revealing [sic] the traditional Indian student's inadequacies rather than inadequacies that would apply to Indian and Non-Indian alike (Green, 1978, p. 3).

This group concluded that it would be more profitable to scrutinize the faculty and the curriculum than to test the students.

Even when viewed as part of the grim statistics on achievement and graduation rates of students of color in general (cf., Council of Chief State School Officers, 1993; National Center for Education Statistics, 1992; Oakes, 1990; U.S. Department of Education, 1994), these data do not begin to convey the scope of difference in performance of Native students. Native students are practically excluded from the picture because of their relatively small numbers in the population to begin with and because of their unfortunately high drop out rate (in some places as high as 60%) (Indian Nations at Risk Task Force, 1991).

Add to these numbers the students who are exempted from testing because their primary language is not English, and the tally reveals a sizable population of students who are not represented in the summary statistics. And, although level of participation in mathematics and science courses is a predictor of achievement, students of color continue to lag behind White peers in performance (Secada, 1991) — even when they continue to take courses. How can we believe we are providing an acceptable educational program when so many students do not achieve at adequate levels? When we see the consistency with which ethnic and racial minority students are disproportionately among those who do not succeed, how can we not make it a priority to look for solutions that address that condition?

Damaging Assumptions

What is perhaps most frightening about such statistics comes from some of our own observations — the extent to which the differential performance of students of color has become a taken-for-granted "fact of life" in some classrooms, despite the near-universal rhetoric of school mission statements that assert, "All students can succeed." This expectation of low performance ranges from "offhand" remarks such as, "Even the Black students did a good job!" to organizational strategies such as placing "high group" White students in the front of the classroom where they receive instruction on the blackboard and "low group" students of color in the back of the room where they complete worksheets and are accorded teacher attention only when they raise their hands and ask for help.

These observations are not surprising within the context of compensatory programs that center on basic skills improvement — the historical solution to the problem of academic underachievement (cf., Cole & Griffin, 1987; Secada, 1991). But, as Secada contends (1991), "it would be bitterly ironic if we succeeded in making our low-achieving children computational wizards while their middle class peers developed other more important competencies" (p. 315). Current reforms, if carried out, will move instruction for all students away from a skills focus toward "the thinking curriculum" (Resnick & Resnick, 1989). However, if efforts to improve instruction for underserved students continue to center on teaching methods rather than on promoting understanding of the sociocultural reality that shapes student performance, these efforts will likely fail (Bartolomé, 1994). Wholesale adoption of prefabricated methods guaranteed to catapult "regular" students into intellectual

excellence cannot simply be applied in the same ways to students who are least well-served at the present time.

Although the existing curricula in mathematics and science have been most blatantly unsuccessful with students from non-dominant groups, the widespread impetus to reform suggests that they have not been appropriate for many other students as well. Some students have simply coped or gone along with the program better than others. The kinds of changes proposed certainly represent a direction that educators advocating for "diverse" students have long recommended: increased linkage between what is taught in school and what is experienced in life out of school (including capitalizing on students' own knowledge bases and situating learning in meaningful contexts), increased opportunity for building on students' interests, and a focus on higher-level thinking for all students. The problem is that surface potential and good intentions will not automatically translate into improved instruction for underserved students. As a Hopi elder explained, "These programs look good on the outside, but they need something on the inside" (Dukepoo, 1993b, p. 3).

Assumptions about deficits based on lack of understanding of socio-cultural influences on learning are particularly harmful in their consequences. The terms "disadvantaged" or "at-risk" are disturbing, because they locate the cause of school failure in individuals rather than in social systems where it belongs or must be examined. Perhaps the term "disenfranchised," which places responsibility on outside forces rather than on the student or his or her social group, would convey the social reality more accurately, though this term risks implying that underserved students are in passive roles only — overlooking their active resistance to such forces. Students who are members of certain demographic groups are, of course, at some disadvantage when they go to school, but disadvantage is not something inherent; it is transactional: students are disadvantaged with regard to something or by something because of the ways education is provided. Secada (1992) says, for example,

> ...it is one thing to note that Hispanics from lower-class backgrounds do not, as a group, perform as well in mathematics as do middle-class Hispanics, or even as well as Whites who are similarly situated. It is another thing, however to argue that being Hispanic from a lower-SES background places one at risk of such an event; that is to say, membership in a group is predictive of a certain event... The prediction that should be made, if there is one, is that unless we modify the educational experiences that students from these backgrounds receive, we will fail to educate them as fully as we believe they can be educated. In and of itself, membership in these various groups cannot predict mathematics achievement later in life (p. 640).

Secada suggests that such an assumption is an example of how our society transforms what is essentially a social issue into a personal psychological issue and how achievement comes to define a student's ability rather than being seen as largely a function of opportunity.

Culture-Based Variations in Ways of Knowing

A constructivist view of learners, one that recognizes students as active meaning-makers, needs to be complemented with a sociocultural perspective that recognizes the importance of social and cultural systems and their associated values and expectations on students' learning. Table 1 on the following page summarizes components of both constructivist and sociocultural approaches to education. We believe that both the constructivist view, which is focused on an individual student's psychological processes, and the sociocultural view, which emphasizes learning in social contexts, contribute to understanding of classroom learning (cf, Cobb, 1994).

Cultures differ in their ways of using language and communicating; in their approaches to problem-solving; in the degrees and ways in which they differentiate, classify, and interpret the natural phenomena they experience or observe. Despite the fact that essential cognitive capacities are apparently universal across cultures and acquired invariantly (Lancy, 1983), particular systems and strategies for extending or amplifying basic cognitive functions (such as through mathematical systems or technologies) are extremely culturally variable and apparently closely linked to the demands of daily life.

According to Lancy (1983), hunter-gatherers and industrialized groups have high requirements for complex cognitive organizing systems because of the quantity of information they must understand, relate, recall and apply. In comparison, agrarian societies, in general, experience fewer information processing demands and may develop less sophisticated information management and memory systems. Lancy (1983) argues that it is the volume of information rather than the nature of the information that pushes development of "more efficient strategies for perceiving, coding, retrieving, and transforming information" (p. 207). When there is a need for such efficient information management, children tend to acquire strategies at an earlier age than in societies where such categories are not as necessary. So, when children from different societies find themselves together in a classroom at age five or six, they may be in very different places with regard to the strategies they call upon for managing information.

Learning styles or approaches are also affected by one's environment and daily life. For example, "discovery learning" may be discouraged in a harsh, natural environment that is fraught with physical hazards, as is the case with many traditionally-raised Native children (Kawagley, 1990; Lancy, 1983). Thus, the kinds of classroom participation demanded by some contemporary teaching and learning methodologies (Green, 1977) may be in direct contradiction to what Native children have been taught. Obedience to parental constraints may be obligatory in a socially dangerous environment, as

Table 1
Constructivism and Socioculturalism

Constructivist Theory	Sociocultural Theory
View of Learning (focus on individual psychological processes)	View of Learning (focus on social situatedness of learning)
Students actively construct knowledge. They are not passive recipients of information based on existing schemata.	Learning is a social act, situated in a social and cultural context, in interaction with other members of a community.
Learning need not proceed hierarchically from simple skills to complex thought: young learners engage in complex thinking.	Students' learning cannot be understood without reference to the sociocultural situation.
Students should be able to participate in the construction of their own curriculum, and set their own learning goals.	Schools have their own cultures, as do the various disciplines, and enculturation into these cultures is one major task of the school. Everything that takes place in school, community, or home is culture-based.
Inferences about the Role of Teachers	Inferences about the Role of Teachers
Teachers should guide and facilitate learning rather than "dispense knowledge."	The job of teachers is to mediate between students' personal meanings and those of the culture(s) of school.
Teachers should be active, inquiring learners themselves.	Teachers need to be cross-cultural experts, facilitating communication among students and between community and school.
Teachers should have professional expertise, engage in design of curriculum, instruction, and assessment.	
Inferences about Curriculum and Instruction	Inferences about Curriculum and Instruction
The curriculum should be concept-based and deep rather than broad.	The curriculum should be meaningful to students, reflecting the values, symbols, and ways of knowing of students' communities, while introducing students to new cultures/cultural ways of thinking.
Classroom learning should be linked to students' experiences, interests, values.	
Instruction should not be piecemeal but should integrate concepts, perhaps across disciplines.	Instruction ought to entail opportunities for students to examine and discuss multiple perspectives and engage in different approaches to learning and demonstrating knowledge.
The curriculum should be guided by a broad conceptual framework rather than a scope and sequence of specific skills.	

Gadsden (1994) has suggested with regard to African-American children in a racist society where children of color cannot expect equal protection under the law. In cases such as these, educators unfamiliar with particular socialization patterns may judge students' learning abilities inaccurately.

Children learn not only the language and lore of their cultures, but they also learn their cultures' theories of language and cognition (Lancy, 1983). They learn what their cultures consider the important ways of using language (e.g., to talk about phenomena, to influence others), when to talk and in what ways. There is research, for example, that suggests that many members of African-American communities, particularly the working class, use a communicative style that devalues the expression of obvious information (Taylor & Lee, 1987; Heath, 1983). Since the difference between what counts as background knowledge that can be assumed or taken-for-granted between speakers and knowledge that requires explanation is to a great extent culturally determined, students may not in fact "share meaning" with a teacher regarding what needs to be made explicit and what does not. Thus, in requests to provide an explanation or recount an event, even directions like "be concise" may mean one thing to a middle class White student and quite another to an African-American whose communicative style may dictate against statements of the obvious.

Storytelling is an important language function in many cultures and is often used to express particular ethical values or to recount the history of a group. However, Native people, unlike middle-class European-Americans, are likely to tell a story without asking children to offer their interpretations of various events as the story is told. Native children are expected to make their own sense of the story; and through years of hearing a story, they will make increasingly mature sense of it. How different from the interactive style of extensive exegesis often modeled in the Western classroom! Other differences in ways of using language or in patterns and styles of communication have been reported in several studies. Domination of talk by a single person (e.g., a teacher) and addressing single individuals within a group rather than addressing the whole group are practices foreign to many Native children (Philips, 1983). A teacher's direct evaluation of individual students' performances in front of the whole group violates norms of many Native communities and may well prevent Native students from willingly responding to questions in the classroom (Eriks-Brophy & Crago, 1993).

Cultures have norms about who should have or express particular knowledge. For example, in some Native groups, certain stories are told to children only when they reach a specified age. Not everyone is privy to the same knowledge — whether through story or demonstration. In the case of some Hopi religious traditions, they are intended for only certain family members and not others. Among many groups there are ongoing debates about whether information on sacred practices and wisdom should be shared with the world beyond the tribe. Some elders believe that if Native children are to

succeed in "both worlds," those beyond their own communities need to understand Native ways more deeply. Others fear that the wisdom of their groups will be denigrated, changed, or co-opted by even the most well-meaning non-Natives.

Children also must learn what knowledge is important for what purposes, and when and how it is acquired and displayed. In an account that demonstrates the subjective, culturally determined nature of "abstract" categories, Frankenstein and Powell (1994) retell a story of researchers working with a group of people whom "academic anthropologists" would label "primitive." The researchers presented five objects from each of four categories: food, clothing, tools and cooking utensils and asked the participants to sort them. Most of the respondents arranged groups of two, explaining practical connections such as "the knife goes with the orange because it cuts it" (p. 83). As cited in Rose (1988), "[the people] at times volunteered that a wise man would do things in the way this was done." When an exasperated experimenter asked finally, "How would a fool do it?" he was given back groupings of the type initially expected — four neat piles with foods in one, tools in another" (Rose, 1988, p. 291).

Such an account is a reminder that when assessment of cognition or achievement does not consider the ways of knowing the group to which the person being assessed belongs, it cannot pretend to have valid outcomes. New forms of assessment such as portfolios and performance tasks may turn out to be more equitable, if — and only if — they allow the flexibility and contextualization necessary to capture the meaning of student performances.

Differences between Native children and European-American children have been noted and sometimes misunderstood, with the result that Native children have been stereotyped as quiet or shy. However, according to many accounts (cf., Green, 1978; John-Steiner & Osterreich, 1975; More, 1989; Swisher & Deyhle, 1987), Native children do tend more towards a "watch-then do," or "listen-then do" strategy than the "trial and error" approach favored in schools. According to a young Keres man cited by Tafoya (1989), "You don't ask questions when you grow up. You watch and listen and wait, and the answer will come to you. It's yours then, not like learning in school" (p. 32).

Science teaching in Native communities presents an interesting context for studying the relationship between the acquisition and transmission of knowledge. Native approaches to science are rooted in naturalist traditions in which primary access to knowledge about the physical world and its phenomena comes through observation and experience. Because Native communities follow traditional subsistence lifestyles, parents routinely expose their offspring to survival routines, often immersing the children in decision-making situations in which they must interpret new experiences and relate what they discover to their growing store of knowledge about the world around them.

Summarizing the findings of a number of studies on the learning styles of Native students, Swisher and Deyhle (1987) point out that Native students "approach tasks visually, seem to prefer to learn by careful observation which precedes performance and seem to learn in their natural settings experientially" (p. 350) — the watch-then do strategy mentioned above.

It has also been claimed that in some cultures, such as Navajo and Chipewyan, it is the adult who displays and the child who listens or observes. Adults do not pay overdue attention to children or correct them, because adults would then need to continually monitor their children's obedience. By ignoring children's behavior, adults ward off threats to their authority (Scollon & Scollon, 1983). When it is time to learn certain things, a young boy may be taken out into the countryside and left all day to learn for himself about the land and water — reflecting an approach of guiding, facilitating, setting up a circumstance through which the child can learn. (Compare this with new conceptualizations of teachers' roles in a constructivist framework.)

In considering what would constitute a curriculum and an approach to instruction that is valid for a given cultural group, we must first consider the customary ways of knowing and acquiring knowledge of that group. We are faced with essential epistemological questions such as, "What counts as important knowledge or knowing?," "What counts as evidence for claiming something to be true?," and "How and when should knowledge or understanding be expressed or shared?" As is evident from some of the foregoing examples, a blanket approach to students that fails to take sociocultural factors into consideration is not likely to succeed in reaching all students.

When essentially different approaches to knowledge come in contact with one another, they may conflict or collide; or they may serve to complement each other. What happens is partially dependent on how children are enculturated to new ways of thinking (as in school). "Elements of cultural knowledge do not create barriers in the study of science; but rather can enhance, excite and stimulate scientific curiosity and inquiry.... Teaching... can engender cultural appreciation, understanding, respect and acceptance" (Dukepoo, 1993a, p. 4). In some ways, the case is similar to that of speaking more than one language: learning a second language gives perspective on the first, expands one's notion of language, and makes for greater cognitive flexibility, if one is supported to maintain the first language and if respect is accorded to that language (cf., Hakuta, 1990). In the remainder of this chapter we will consider how "Western" and Native ways of knowing in the areas of mathematics and science differ and what might be done to help Native students understand both.

Cultural Bases of Mathematics and Science Knowledge

Most people can quickly grasp the idea that history is somewhat constructed, with emphasis given to certain events over others, depending on who is looking back — or that the interpretation of a single event varies, relative to one's group identity. However, mathematics and science are often

assumed to be neutral, objective, precise, and universal (cf., Bishop, 1991; D'Ambrosio, 1987; Diop, 1991; Fasheh, 1991; Frankenstein & Powell, 1994). That is, they are culture- and value-free (notwithstanding their applications to building bombs and creating environmental pollutants, or to curing diseases and designing objects of beauty). But what is the likelihood that "no social values, no human hopes and aspirations are present in human thought about nature" (Harding, 1991, p. 81)? In fact, we argue, there is no realm of human knowledge that is free of interpretation and value. Scientific knowledge is both symbolic and socially constructed. "The objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature" (Driver, Asoko, Leach, Mortimer & Scott, 1994, p. 5). Of course there are commonalities across different cultural constructions because of the fact that there is an empirical basis for them: all human beings live in the same physical world. Moreover, all humans have the same brains.

The Mixed Heritage of "Western" Mathematics and Science

Another assumption is that Western mathematics and science represent the culmination of a long, direct line of European thought originating with the Greeks, when in fact the development of mathematical thinking, in particular, derived from multiple sources over a period of thousands of years. Contributions from Arabic cultures, Persians, Chinese, Indians, Egyptians and others were integral to what is now thought of as Western mathematics. That the lineage was not direct is also clear, for example, from the need to rediscover Roman-era theories of the universe (heliocentrism) via Arabic documents retranslated into Latin (Levidow, 1988) in the time of Copernicus, Galileo, and Kepler. There are many other instances of circuitous routes of travel of mathematical, scientific, and technological knowledge eventually incorporated into Western knowledge bases.

The British were apparently not content with appropriating the knowledge of others but "sought to delegitimize and even destroy" the known non-European cultural heritage of such knowledge (Levidow, 1988, p. 113). Beginning in the middle ages and for the following centuries, plants that had economic potential, Indian-made steel, Asian textile techniques, Indian arithmetical and numerical forms of notation — among other things — were all appropriated by the Europeans, with little attention to crediting their sources. Even now, plants used by indigenous groups for medicinal purposes are represented in Western medicine as the West's own discoveries. Speaking of recent research by U.S. pharmaceutical companies with indigenous herbs, Levidow (1988) says,

> If successfully marketed, the pills' brand name would obscure the indigenous origin of their ingredients — not just the herbs but also the knowledge that selected and cultivated them. Thus continues the process of usurping and then marginalizing non-Western science, of turning its achievements into forms of private property, separated from popular knowledge and control. .. But it is not too late for us to challenge the values that

have shaped the officially legitimized knowledge of our society. A sympathetic but critical study of living folk medicine traditions could contribute to that challenge. (p. 115-116)

Assumptions Regarding the Nature of Mathematics and Science

"Western" Mathematics and Science: A Particular Way of Knowing

Western mathematics as taught in American schools can be characterized as "rational," that is, emphasizing deductive reasoning and not relying on "trial and error pragmatism, rules of practice, traditional wisdom, inductive reasoning and analogistic reasoning" (Bishop, 1988, p. 62). Above all, mathematical thinking should be logical — as should all argumentation, according to Western values. (Science, on the other hand, is more focused on external, empirical proofs (Bishop, 1988)). Another feature of this rational approach is the separation of object from idea. Unlike the Navajo way of viewing reality, with its focus on processes and phenomena in flux, current Western mathematical thinking is situated in a world view that posits discrete entities and quantities. Bishop (1988) calls this value "objectism" (p. 64). It is interesting that — like the Navajos — certain pre-Socratic Greek mathematicians and philosophers, such as Heraclitus, were more interested in process and change than in particles; however, the "atomists" prevailed among the Greeks (Bishop, 1988). Western thinking, in general, tends toward decontextualizing, depersonalizing, and dehumanizing experience and natural phenomena. Although this approach distinguishes between concepts and objects, it then turns around and treats abstractions as objects to be manipulated or operated on. As Bishop (1991) has said, "one of the ways Western mathematics has gained its power is through the activity of objectivizing abstractions from reality. Through its symbols (letters, numerals, figures), mathematics has enabled people to deal with abstract entities as if they were objects" (p. 36). This approach has its advantages and disadvantages, as we shall see.

In Pythagoras's time, numbers were objects — points, stones, particles.[1] In like fashion, the points of an argument — (axioms) — were thought of as the particles of reasoning from which complex propositions, or proofs, were constructed. Another tendency of objectism was to look for mechanistic explanations of natural phenomena, to envision reality as "some kind of complex mechanism, with nature being composed of objects moving in ways akin to machinery" (Bishop, 1988, p. 68). Mathematics was influenced by this world view and also contributed to it through its applications in the physical sciences. These values of rationalism and objectism permeate dominant modes of thinking. One of the consequences (though it is hard to separate cause and effect here) of an "objectizing," decontextualizing approach is a loss of connection to social meanings and realities, or as Levidow (1988) has said, a loss of the "ethical frameworks" that had guided people's views of what was socially useful or what constituted progress (p. 102). While there is intellectual value in being able to represent abstract relations purely through symbols and to manipulate those relationships without reference to context — providing powerful, generalizable tools for interpreting and predicting natural phenomena — there is a danger in abandoning awareness of

[1]Some numbers or quantities had strong conceptual force. As in Dakota, Navajo and Hopi cultures, "fourness" was particularly important: there were the four worlds; four essential elements of earth, air, fire and water; the four geometric elements of point, line, surface and solid. In early Navajo and Hopi conceptualizations of the world, the four directions, and four colors of corn, e.g., held special meaning. (cf., Benally, 1988; Ortiz, 1972; Tedlock & Tedlock, 1975; Waters, 1963).

the real-world contexts in which those relations come to bear (cf., Hall, 1976). The fact/value distinction is artificial: there are no facts that can be abstracted from context and still retain meaning. Value is always present.

Culture-Based Variations and Standards

Bishop (1991) notes that all cultures generate mathematical (and scientific) knowledge, but that knowledge need not look the same from one group to another. In fact, mathematics and science must be understood as kinds of cultural knowledge or cultural products rather than as objective bodies of truth. Much of mathematical activity is social, constituting a special form of human discourse. According to Wheeler (1993), "a crucial part of mathematical activity is concerned with persuading, arguing, proving: processes that can only be carried on when other people are involved, in social groups in communities which own a common language" (p. 90). Therefore he prefers the term "knowing," which communicates an active, personal connection; only people can know and operate on what they know. "Knowledge " seems static, impersonal — divorced from people and social contexts.

One might say that mathematical and scientific knowledge or ways of knowing are both "discovered" and "invented" in that there are common threads across cultures, rooted in "invariant logical structures" (Nunes, 1992, p. 558). "It is the ability to make inferences using these [invariant logical structures] — not the content of knowledge — that distinguishes mathematical knowledge" (Nunes, 1992, p. 558). Just because humans "discover" a certain cognitive system that seems to capture or serve reality does not mean such a system is a universal given, i.e., a complete guide to reality. Humans are limited by the perceptual, processing, and cognitive capacity of their brains; it is not possible to have objective or perfect knowledge about the universe and its "laws."

Throughout all cultures that have been studied, six major mathematical activities are universally present: counting, locating, measuring, designing, mathematical game playing, and explaining (Bishop, 1991). Understanding logical relations, ordering, and classifying are also likely candidates for universality. Different cultures (and indeed, occupational groups) have different systems for handling these mathematical functions. Those that deviate from the Western academic mode are often seen as incomplete or inferior approaches rather than evaluated in the context of their adequacy to serve the purposes of the society that developed them. Moreover, intellectual inferiority cannot be inferred on the basis of what might be considered "primitive" mathematics or other cognitive systems because of people's capacity to learn — given motivation and opportunity. Considerable cross-cultural research shows that "advanced" skills can be taught to those who do not have them (cf., Anderson & Clark, 1978), when instruction provides steps to bridge conceptual differences. Level of cognitive performance is heavily task-related, not a constant (cf., Scribner & Cole, 1981); and people may have the ability to engage in certain "high-level" cognitive skills but not choose to do so in particular circumstances (Lancy, 1983). In encountering a different cultural context, learners are inclined to rely on the habits of mind and strategies

developed in their own communities. In fact, "competence" might be said to depend upon the match between the demands of a task, the context in which it is embedded and the culturally-developed skills of the learner (Gallagher, 1993).

Children within a culture are enculturated to the values that guide the understanding of the meaning of mathematics, science, and other activities. In school, students are enculturated to scientific and mathematical discourses and practices that intersect to varying degrees with the scientific and mathematical discourses of their own home cultures. Learning is, to a large extent, a matter of being introduced to and making sense of a symbolic world inhabited by conceptually organized, rule-bound belief systems about what exists, how to achieve goals, and what is valued (Driver et al., 1994). So, in a sense, all students are faced with learning the norms of numerous cultures and social institutions. However, for some students, extra cultural layers may provide both challenge and opportunity.

When we pretend that domains of knowledge as taught in schools are neutral — i.e., not attached to particular ways of thinking, valuing, and knowing — we excuse ourselves from acknowledging other equally valid perspectives and epistemologies and from creating ways for children to make connections and comparisons between different ways of knowing.

> The belief in a best and universal path is detrimental to the richness which is manifest in life and in communities as well as to the production of conceptions, practices and attitudes (including those in math and science) which are meaningful and relevant to the majority of people (Fasheh, 1991, p. 61).

Speaking as a member of a Third World community who was educated in the Western tradition, Fasheh goes on to say,

> Continuing to accept Western math and science as universal and authoritative is detrimental to creating a healthier and more humane world. Like other activities, math and science need to be treated in a critical way, not only at the implementation or application stage *but also, and more importantly, at the level of the basic premises and values governing conceptions, practices and production* (p. 60, emphasis added).

European-Americans tend to view societies and disciplines such as science and mathematics as moving inexorably toward more complex ("advanced" or "better") states. Time is sequential, linear; and what is to come will be better than what went before. This view (counter to a more circular view of time held by Native cultures) blinds us to possibilities and prevents us from truly examining current ways of thinking. If, by definition, current ways are better, we cannot even entertain the possibility that something that came

before is of equal or greater value. But again, the very questions asked by science are influenced — if not determined — by their social context. Scientific knowledge is not objective. The objective-subjective dichotomy itself is as artificial and unmaintainable as the myth-history dichotomy. Harding (1991) suggests:

> Science is more than politics, of course, but it is that. It is a contested terrain and has been so from its origins. Groups with conflicting social agendas have struggled to gain control of the social resources that the sciences — their "information," their technologies, and their prestige — can provide. For those who have suffered from what seem to be the consequences of the sciences, their technologies, and their forms of rationality, it appears absurd to regard science as the value-free, disinterested, impartial, Archimedean arbiter of conflicting agendas, as conventional mythology holds (p. 10).

Factoring Cultural Variation into Pedagogical Reform

Introducing Other Perspectives into the Curriculum

The Western approach serves to obscure important social information in technical facts that purport to be value-free.

> With a cross-cultural perspective on the value choices made by science, we will be better equipped to recognize the hidden political content of Western science, as well as to find new knowledges needed for creating alternatives to a 'life' based on the cash nexus (Levidow, 1988, p. 117).

We may find Levidow's judgment a bit harsh, but we will be hard-pressed to argue with the need to look below the surface to examine the values implicit in Western ways of doing/knowing mathematics and science.

It must be clear that what we are talking about goes much deeper than incorporating mathematics and science from different cultural communities in a curriculum that offers no perspective on the assumptions underlying Western mathematics and science. A truly cross-cultural perspective that gets at core assumptions will better equip students to recognize the values embedded in Western science and to identify the information required to understand alternatives. (Levidow, 1988).

Western culture is in somewhat of a predicament. Its unchecked resource consumption and creation of environmental hazards have led to economic and health problems for its own citizens as well as others throughout the world. Although many technological advances have been used for positive ends, the West has not been able to combine scientific advances with the insights and human values necessary to contain the ill effects of its technologies (cf., Hall, 1976). And Western culture has certainly not succeeded in fully educating its citizens to a level of scientific literacy that includes both technical understanding and the ability to engage in thoughtful and critical evalua-

tion of the uses of scientific discoveries (the ethical dimension of scientific literacy). The critical philosopher Habermas has observed, "The capacity for control made possible by the empirical sciences is not to be confused with the capacity for enlightened action" (Bishop, 1988, p. 56).

As a rule, the non-dominant approach to any domain or question is assimilated to the dominant (or the dominant is used to interpret the non-dominant). Another way of characterizing the process is stated by Sleeter (1993): "[d]iverse groups (or rather their discourse) are incorporated into a grand narrative" (p. 5) that serves to maintain the existing order. By the ways in which mathematics and science are taught and used as gatekeepers to access to power in the society, and because they can perform material functions successfully, they (including technology) "generate a system of control" (Fasheh, 1991, p. 59). There is an ideological dimension, a relationship between what formal education takes as its purview (and what it excludes) and power in the society. In attempting to empower students from non-dominant groups in the ways of knowing/being/doing of the so-called majority, we must be cautious not to alienate them from their own cultural ways of knowing. If one's sense of worth and right of choice come to depend on buying into dominant [hegemonic] ideology, what may be lost?

However, acceptance of the premise of multicultural or democratic education does not lead to automatic solutions to the problems we have outlined. There are potential pitfalls in the enterprise of accommodating multiple epistemologies, world views, and values within a curriculum. Other content areas, such as history and social science, have already attempted to tackle this issue, and they offer tremendous insight into the problem. Sleeter (1993), speaking of the teaching of history, contends that representations of knowledge are "centered" in the sense that they arise from a particular vantage point, and "[t]he reference point with which one centers and begins a story shapes the entire subsequent story" (p. 9). Regarding the classroom, one might ask whether all views are examined relative to that center, or whether multiple possible centers are acknowledged. Prime examples of "dominant culture centering" are American history texts that presume a single point of departure or origin of American history (such as European colonization of the American continent). Mexican-American and Native students whose American history goes back hundreds or thousands of years prior to the European invasion may find such a centering odd or exclusionary of their experience. A single-centered approach substitutes one narrative for a multiplicity of possible narratives that would originate from different experiences and have equal validity as representations of history (cf., McLaughlin & Tierney, 1993). We should also think about where we are centering the beginning of educational reforms.

Native philosopher Vine Deloria posits that in similar fashion a Eurocentric, positivist science is taken to be the only valid approach to gathering and organizing knowledge. Other ways of knowing are viewed as incomplete versions of science, missteps along the way to modern thought, or valid only to the degree that they correspond to present beliefs. Deloria (1992) notes

that dominant-culture interpretations of Native science do not recognize the "whole basis on which tribal peoples acquired their insights" (p. 17). For example, tribal science seems to have had no intention to separate the observer from the observed, something Western science is slowly coming to recognize as impossible in any case. Another contrast is the way in which tribal peoples have tended to refrain from abstracting broad generalizations from experience and then using them to explain new experiences or make predictions. Instead, they have understood new information and experience in terms of the full tapestry of continuous experience and contextualized knowledge. Instead of matching generalizations with new phenomena, Native people match their more specific body of information with the immediate event or experience. In this way, they do not risk oversimplifying or reducing the meaning of a complex experience or understanding.

Lipka (1994) cites an excellent example of the maintenance of contextual information in biological classification (from Fall, Chythlook, Schichnes & Morris, 1989). Yup'ik Eskimo children are socialized to use fat content and function as markers for categorizing fish types. Much information would be lost if these children were only to learn Latin genus and species terminology that did not convey important contextual information about the fish.

Oscar Kawagley (1990) characterizes Yup'ik cultural thinking processes as spiritual, pragmatic, and inductive. Kawagley explains that in Yup'ik culture, natural phenomena are explained in terms of "readily observable characteristics or experiences involving a high degree of intuitive thought." He points out that many of the skills that are instilled through the Yup'ik culture — for example, participation and interaction with nature — can be useful for the teaching of mathematics and the natural or physical sciences. He suggests that Western approaches to the teaching of these subjects can be "too alienating from the natural world" and therefore alienating to Native youth. Learning about nature from books can seem a poor substitute for the real thing. We see that there are fundamental differences that cannot be attributed to a defective version of modern science but that derive rather from an entirely different world view and body of experience.

If we evaluate the contextualized, personal approach to knowledge (as distinct from an analytical, depersonalized approach) only in terms of a European definition of science, we fail to see the system on its own merits, with its internal consistency and utility. According to Deloria "[t]he initial approach to experience, the process by which we identify data as important or irrelevant, determines how we choose to connect experiences and facts. We formulate the subsequent patterns of arrangement and interpretation which we impose on experience after this initial identification" (p. 15). (Compare this process to "centering," mentioned above.) No wonder that the interpretations resulting from different approaches are not equivalent; nor can they be judged according to the same criteria.

To be sure, if we succeed in using the era of educational reform in the United States as an opportunity to evaluate the very foundations of Western mathematics and science and the way they are taught, the disciplines may change fundamentally. As Harding (1991) has observed vis-à-vis the entry of women into new workforce arenas,

> [i]n the humanities, biology, and the social sciences, it turned out to be impossible to 'add women' without challenging the foundations of those disciplines. Similarly, the feminist science critics argue that when we try to 'add women' as knowers within traditional theories of knowledge, we quickly discover how partial and distorted are those theories (p. 47).

What might the outcomes be, if in parallel manner new cultural perspectives were actually heard and taken seriously? Much is to be gained for all members of our (U.S.) society by broader and deeper perspectives on our own multicultural history and the multiple epistemologies and sources of knowledge that have led us to the present realities — both inside and outside schools. In fact, if students are to become critical thinkers who can integrate complex concepts across domains, they need to be able to evaluate sources of ideas and ways of constructing knowledge as well as process information. If complex social, technological, and political issues in what is increasingly understood to be a global society are to be grasped and dealt with — and if the United States is to take positive leadership — all citizens in our democracy need to gain the kinds of historical and cultural insights of which we speak.

> The challenge lies in fostering a critical perspective on scientific culture among students. To develop such a perspective, students will need to be aware of the varied purposes of scientific knowledge, its limitations, and the bases on which its claims are made. A crucial challenge for classroom life is therefore to make these epistemological features an explicit focus of discourse and hence to socialize learners into a critical perspective on science as a way of knowing (Driver et al., 1994, p. 11).

Of course, the same can be said of mathematics.

Dominant culture educators may take a benevolent, inclusionary stance toward other epistemologies — allowing them to be investigated as historical artifacts or interesting deviations. But, as with the social sciences, the "grand narrative" (Sleeter, 1993) of the dominant culture is not likely to be displaced or even modified via such an approach. There are strong assumptions about what will remain at the core of the curriculum. This is why "infusion" as usually implemented is a weak multicultural model. In the deepest sense it allows the dominant curriculum to remain undisturbed — modified only around the edges, not at the core. As Deloria points out, the science of tribal peoples has been systematic and not a random collection of pieces of nature

lore, something infusion of a few "Native" activities inadvertently suggests. We would do better to consider and teach such "alternative" systems in a broader context, as systems in their own right rather than as relative to the dominant mode or in terms of the dominant approach. The task for teachers then becomes one of helping students mediate between their personal meanings, their own culture-based systems, and the systems of school.

The Role of Ethnomathematics and Ethnoscience in the Classroom

Ethnomathematics has been defined as *forms of mathematics embedded in cultural activities*, forms that vary from culture to culture (Nunes, 1992). Likewise, ethnoscience can be conceptualized *as forms of scientific and technological activities in their social and cultural contexts*. "Culture" is not restricted to ethnic group here; rather, it is meant to include workplace and social groups as well. In social contexts, in real life, mathematics and science are not used for their own sake but to carry out everyday tasks and solve everyday problems (Nunes, 1992). As Geoffrey Saxe (1988) has observed,

> What comes out of the accumulating research on out-of-school practices is the view that mathematics learning is not limited to acquisition of the formal algorithmic procedures passed down by mathematicians to individuals via school. Mathematics learning occurs as well during participation in cultural practices, as children and adults attempt to accomplish pragmatic goals (pp. 14-15).

Builders attempting a new design, textile workers experimenting with different materials, basket makers needing to speed up a technique may create practices that develop into methods that may or may not be "mathematized" and/or evolve into theory — but these workers are *using mathematics*. In many cases, practices are not translated to theory and die out when social circumstances change (D'Ambrosio, 1991). But it is important to bear in mind that whose activities count as mathematical and what counts as mathematical knowledge have to do with the "politics of knowledge" (Frankenstein & Powell, 1994). The ways of knowing that are privileged in any society are determined by the power relations among groups in that society.

With ethnomathematics (or ethnoscience), "the chain of historical development, which is the spine of a body of knowledge structured as a discipline, is not recognizable. Consequently, ethnomathematics is not recognized as a structured body of knowledge, but rather as a set of *ad hoc* practices" (D'Ambrosio, 1991, p. 22). As Borba (1990) has observed, the forms of ethnomathematics developed by different groups are likely to be more efficient at solving problems related to their cultures than academic mathematics is, because the ethnomathematics developed by a given cultural group reflects solutions to the particular obstacles encountered by that group. Ethnomathematics should be understood as cultural expressions of mathematical ideas — ideas that have survived largely through oral transmission.

Saxe (1988) has studied the ethnomathematical practices of Brazilian child candy sellers. These children develop sophisticated methods for making decisions about how much candy to purchase (at what prices), how to price candy for sale — using ratio schemes for multiple units (e.g., 3 bars for 1000 cruzeiros) and factoring in Brazil's inflation rate, which was at the time of the studies quite high. Many of these children have had no formal schooling and may use non-standard techniques for representing numerical values or carrying out operations, yet they are very efficient in their sales practices. They are accurate in their calculations, in identifying and comparing bills of different denominations, and in handling multiple pricing ratios (giving a break to customers who buy in large quantities rather than small). These children are using mathematical practices that are entirely useful for their purposes.

Some educators look directly to ethnomathematics and ethnoscience to serve as the sources of real-world connections that will make classroom theories and procedures meaningful (Bishop, 1988; National Council of Teachers of Mathematics, 1989; Nunes, 1992; Wheeler, 1993). Others, while not directly mentioning "ethnomathematics" or "ethnoscience," suggest classroom mathematical or scientific investigations that build in some way on students' knowledge and lived experiences (Mathematical Sciences Education Board, 1989; Ovando, 1992). "All children bring with them to school a base for scientific knowledge, skills and experiences. And this base can be related to the school's curriculum," (Ovando, 1992, p. 223) making classroom mathematics "transparent and functional to them" (Saxe, 1988, p. 20).

Mathematics educators such as Wheeler (1993) and Schoenfeld (1985) have proposed that students have the opportunity to "function like mathematicians," discovering for themselves various principles, making mathematical knowledge their own rather than absorbing pre-digested information; and this goal is reflected in the NCTM standards. If students are to "check and validate their own beliefs" and to become less dependent on authority and achieve autonomy (Wheeler, 1993, p. 92), meaningful activities that bear some relation to their everyday lives should contribute a basis for such autonomy. The point is that students understand mathematical concepts in their own terms, be able to apply them freely in contexts that are meaningful to themselves and have the procedural know-how to do so. In fact, constructivist interpretations of education rest on the belief that students must construct their own knowledge — not simply receive it. By extension, one might argue, as Freire (1970) has, that students should actively participate in the actual design of their own pedagogical programs. According to Freire (1970), "The content of an education for critical consciousness must be developed by searching with the students for experiences which give meaning to their lives" (p. 28). If the central elements of thinking like a mathematician are incorporated in mathematics classrooms, mathematics instruction will become more like some approaches to science instruction that focus on inquiry and discovery.

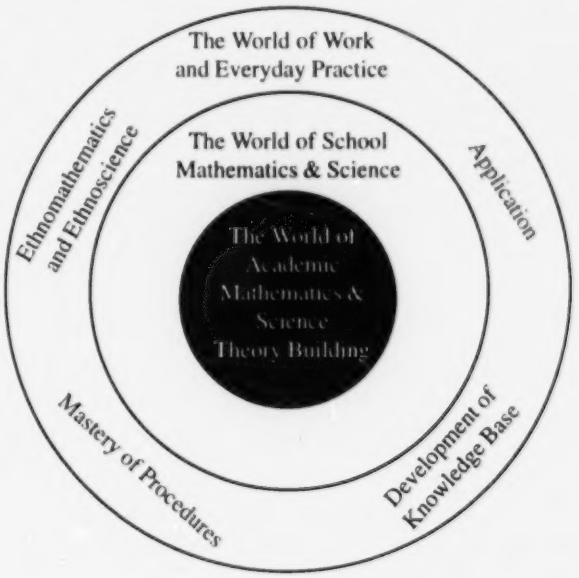
The apparent value of incorporating ethnomathematical and ethnoscientific activities from students' communities lies in their potential for showing connections to common conceptual underpinnings and/or ways in which epistemologies converge or diverge. Such a move goes well beyond the sort of cultural validation educators seem to assume leads to student self-esteem, and which they justify on those grounds alone. However, we must ask, "What are the relationships between mathematics and science as taught in schools and ethnomathematics and ethnoscience — lived practices in social contexts? How does one set of practices and ideas inform the other?"

When ethnomathematics and ethnoscience are transported from their natural environment into the classroom they may lose some of their authenticity. That is, the immediate need to engage in such practices is lost; and an activity may seem contrived. On the other hand, if students are engaged in posing problems for the classroom that require mathematical and scientific thinking — or if teachers pose for them legitimate problems that relate to their own lives outside of school — meaningful learning may occur. Project-based mathematics and science curricula constitute one approach designed to engage students in authentic, real-world problem-solving (Madfes, 1994).

Everyday mathematics (also called "popular" (Dowling, 1991)), ethnomathematics, classroom mathematics and the mathematics of academic mathematicians have been associated with different social institutions or settings as well as with different functions. Production of mathematical knowledge has been charged to academic mathematicians primarily; reproducing and transmitting that knowledge has been the purview of schools; operationalizing the knowledge occurs in everyday life and the workplace (Dowling, 1991). To a large degree, the same relations appear to hold for science. (Figure 1 depicts these realms of mathematics and their perceived responsibilities.) Yet, the reforms call for mixing it all up! Students would behave both as mathematicians and as everyday users and workers in the classroom — not just as recipients of mathematical knowledge.

To make matters worse, not everyone agrees on what it means "to function like a mathematician" (Tyson, 1994). The idea of promoting students' "thinking (and behaving) like mathematicians" is not new; in fact, it was associated with the New Math movement of the 1950's and 1960's. But there are different conceptions of what it is to think like a mathematician. Tyson (1994) notes that there is no agreement among mathematicians themselves on what "thinking like a mathematician" means. She suggests two possible interpretations: 1) "a conception of students as mathematical investigators, motivated by their own curiosity and excitement, who explore and justify their own mathematical ideas with the ultimate aim of making sense of the mathematical terrain under examination;" or 2) "a conception of students as exploring and discovering mathematical understandings that are new to the field of mathematics" (pp. 2-3). Alternatively, students could be re-discovering mathematical understandings already known to the field of mathematics but not to themselves. Lampert (1990) has stressed the importance of students' becoming

Figure 1
Traditional Institutional Division of Mathematics and Science


The World of Work and Everyday Practice
The World of School Mathematics & Science
The World of Academic Mathematics & Science Theory Building
Ethnomathematics and Ethnoscience
Application
Mastery of Procedures
Development of Knowledge Base

conscious authors and judges of their own ideas and those of their peers. Perhaps the primary goal mathematics educators have in mind when they suggest that students should think like mathematicians is that students should not see mathematics knowledge as a fixed set of "unchanging truths" and procedures to be memorized (Lampert, 1990) but as something to be engaged in, something to which they can apply their own thinking and experience.

Greeno (1988), among others, sees the classroom as providing a key element to students' behaving and thinking like mathematicians, that is, as providing the social setting for a subculture of mathematics in which students can experience the mathematics that is inherent in daily situations. He stresses the importance of students' acquiring a practice of mathematics and cognitive strategies for using it, rather than a static body of knowledge. A "practice is an everyday activity, carried out in a socially meaningful context in which activity depends on communication and collaboration with others and knowing how to use resources that are available in the situation" (Greeno, 1988, p. 24). This concept overlaps with Fasheh's *praxis* — a dynamic, contextualized use of mathematics. Whether educational theorists or mathematicians can come to agreement on definitions or not, there is a core of common thinking in these conceptualizations that converges with a social constructivist view of the learner and pushes us toward incorporation of ethnomathematics in the classroom.

And what about workplace mathematics from the point of view of its users? The research of Jean Lave (1988) and others concerned with "situated cognition" has shown both how workers, artisans and people engaged in activities of daily life successfully use what can be characterized as ethnomathematical practices and how they do not consistently apply those same mathematical operations out of the familiar contexts in which they customarily use them. Lave argues that the context shapes the practice, that it is not possible to separate the two. One cannot talk about mathematical knowledge outside of context, even if that context is the academic world. Dowling, too, (1991) argues that the social context in which "apparently mathematical" practices are used makes a great deal of difference to what those practices signify. Many workers, interviewed about the mathematics required for their jobs, fail to see the mathematics in what they do — whether it is measuring lengths of carpet, packing articles in tessellated patterns, or weighing fluids (Dowling, 1991). They may memorize algorithms for carrying out procedures; but they do not see the connections to the mathematics they were taught in school, unless prompted to do so. Dowling goes further to suggest that the discourses of school mathematics and workplace mathematics and the mathematics of everyday life are discontinuous; however, the research of Saxe (1988) suggests that it is possible for students to transfer understanding from one realm to another.

Mathematics educators themselves may see ethnomathematics or everyday (popular) mathematics as diverging from "real" mathematics, and as

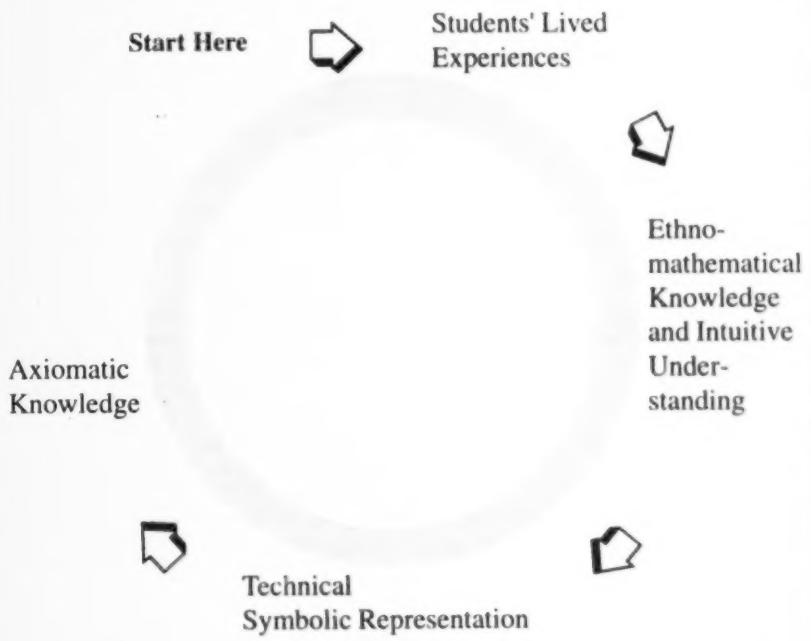
being inferior, if not pathological or abnormal (Wheeler, 1993). So, how are we to cause the membranes separating the different institutions and their ways of operating to be permeable and do so in a way that is not entirely artificial but results in the kind of deep understanding of the relationships among theory, procedural knowledge, and application that we seek to foster in students?

Some have claimed that there is an important distinction between everyday applied mathematics and the mathematics of the classroom. This is that in everyday life mathematical concepts are used as tools (and are to some extent transparent, in the same way that language in use is transparent), whereas in the mathematics classroom they are objects of study (Nunes, 1992). They may also be used as tools to solve contextualized problems in the classroom, but the focus tends to be on the concept, rather than the situation (Nunes, 1992, p. 571). Developmentally in children, use of a concept or system as a tool precedes treatment of it as an object (Karmiloff-Smith, 1988). Children cannot be expected to represent concepts to themselves without experiences in applying those concepts. The implication is that teachers need to draw upon everyday experiences or provide such experiences, then help students see the underlying concepts and how to represent them formally (e.g., how to write fractions). Traditional mathematics instruction has taken the opposite approach: present the concept, then give some applications. Figure 2 shows an instructional sequence that would be compatible with the notion of building from students' experiences through their intuitive knowledge (based on everyday experiences) to more symbolic and axiomatic ways of thinking and representing mathematical knowledge.

Dowling (1991), however, takes exception to the "utilitarian" view that school is to provide students with the mathematical tools they will need when they go out to work or to solve daily problems, precisely because of the discontinuity of discourses from realm to realm. It does not appear that students routinely take the concepts they have learned in school and apply them mathematically to their work or home environments. Some people undoubtedly do solve problems mathematically, and perhaps instructional reforms will result in more people's doing so; but many people are operating with what Dowling (1991) calls "frozen mathematics" (p. 96) — automatized, non-mathematized routines — rather than "living" mathematics (Dowling, ibid).

In some cases, it is not clear that explicit connections between school mathematics and science and real-world applications are necessary or sensible. If, for example, rote algorithms that are "demathematized" serve the purposes to which they are put in the workplace, is there a need to unmask the way they operate mathematically, so that users have a formal representation of what they are doing? Do scientists and engineers always need to understand the deepest principles of the formulas they use or surgeons the arcana of laser physics (cf., Dowling, 1991)? And what effect does it have on a culture to have its ethnomathematical and ethnoscientific practices translated into

Figure 2
Suggested Instructional Sequence for Mathematics



Western academic terms? Do members have a choice? If links are to be made between particular cultural forms of mathematics and classroom practices, what kinds of knowledge do teachers need to have? Some implications seem more clear than others. For example, if a Yup'ik child has learned counting games reflecting a base 20 system, and the teacher knows this, he/she can likely anticipate both how this might help and hinder learning a base 10 system. In fact the Ciulistet, a cadre of Yup'ik teacher-researchers in southwestern Alaska, is currently developing an approach that is focused on making such linkages based on culturally and linguistically embedded knowledge (Lipka, 1994). However, if the child's culture has the view that cause and effect are inseparable and unanalyzable, the implications for "Western" science instruction may be less direct. An essentially different epistemology is being introduced (not the case with the different bases).

One way of thinking about the "elements of mathematical knowledge building" has been suggested by Kieren (1992). Kieren places ethnomathematical knowledge at the core of a set of elements, with intuitive, technical symbolic, and axiomatic deductive knowledge expanding around that core. In other words, the heart of mathematical understanding is mathematical activity based in daily life.

Implications for Teaching Native Students

These observations suggest that a simplistic adoption of an ethnomathematics approach as a solution to the need to create a culturally-responsive mathematics curriculum may not succeed. One risk is that of failing to understand non-European cultural practices on their own terms, of imputing mathematical categories to those practices that members of the culture may not claim (Dowling, 1991). For example, to insist on finding mathematics in basket-weaving may be a case of "the hegemony of European rationalism," (Dowling, 1991, p. 106) and may result in the devaluing of the cultural practices as perceived by those who engage in them. Likewise, we may tend to devalue everyday ethnomathematical practices, such as those shoppers use, unless their users understand them in "school" mathematical terms. But is an activity any less important, valid, intelligent, or understood by its users if it is not captured in formal mathematical terms?

In addition, although mathematics education reform has emphasized 1) connecting classroom math with applications in daily life and the workplace, and 2) giving students the opportunity to behave as mathematicians, the relationships among these pieces and the curriculum as well as how they translate into instruction may not be so obvious. We may be able to identify the underlying conceptual similarity between adding the prices of goods in the marketplace mentally or orally — where hundreds, tens, and ones maintain their value — and adding a column of figures, where "carry the one" can refer to any place value; but how are we to help a student make the connection between the two ways of adding?

We may advocate teaching in ways that allow Native students to bridge gaps between their own world views and the mathematics and science

of school through ethnomathematics and ethnoscience, but we must acknowledge that doing so is not a straightforward task. As discussed, the research and theory surrounding the issues we raise suggest that despite parallels that can be construed mathematically among everyday, workplace, school and higher academic realms, fundamental differences in ways of operating make these parallels vague for many people. However, despite the questions we have raised, we believe that it is the best course pedagogically to begin mathematics and science instruction with students' lived experiences — that is, with ethnomathematics and ethnoscience as produced in their own communities. Such an approach is responsive to both constructivist and sociocultural principles of learning.

In our vision of the classroom, students would learn how to represent and solve problems and to conduct investigations related to their own interests and past experiences, with one goal being to learn the formalized language and procedures of academic mathematics and science as well. We also infer from cognitive development research that starting with experience and working to understanding concepts and procedures may be more appropriate than the reverse for *all* students (as shown in Figure 3). Rather than introducing a new concept by asking students to read about the topic, a teacher might ask students to describe their own experiences, observations, and interactions with the topic first (cf., Pomeroy, 1988). Native students often know much about science related to preserving and maintaining the environment — management of water pollution, toxic waste, agricultural and industrial chemicals and wise use of technology (Preston, 1991, p. 50). However, explanation, discussion, and elaborated experiences will surely be necessary to help students see the relations among ordinary problem-solving activities that can be seen as entailing mathematical and scientific concepts and procedures and the mathematics and science of the classroom or academy.

Because ethnomathematics and ethnoscience offer the potential for an active classroom role for each student, by virtue of being more familiar to the students than teachers in most cases and of requiring the students' interpretation, they are an attractive route to motivating the acquisition of "school" mathematics and science.

Examples of Ethnomathematical and Ethnoscientific Instruction

We must bear in mind, however, that apparent links across the "membranes" of these different realms of theory and practice may not be evident to students. Teachers will want to ask students to talk about the connections they see and about how they would go about solving a particular kind of daily problem out of the classroom. Then, perhaps with the teacher's coaching, they can talk about how they might solve the problem using mathematics they have learned in school. The point would not be to invalidate an ethnomathematical or ethnoscientific (or demathematized) solution, but to explore the pros and cons of such a solution versus a "classroom" solution.

In the following section, we present activities that incorporate elements of ethnomathematics and ethnoscience activities that have been used to

bridge "school" mathematics and Native students' experiences. They illustrate both more and less successful ways of applying ethnomathematics. These activities require students to make school interpretations, i.e., to use formalized procedures to accomplish tasks whose requirements might go unrecognized as mathematical or as having mathematical elements to them.

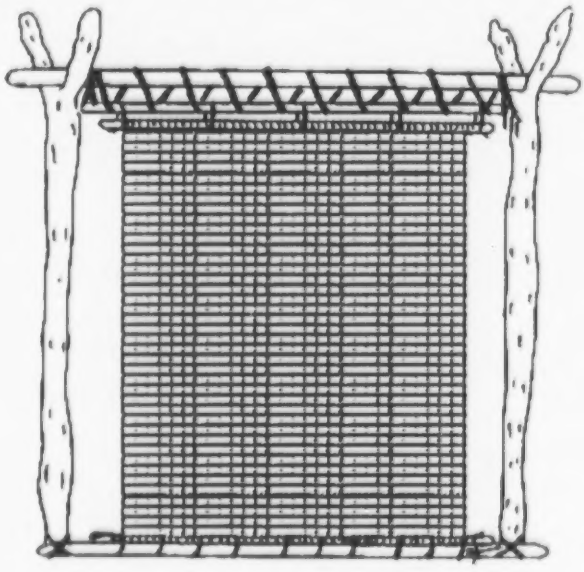
Designing rug patterns and mathematically interpreting existing rug patterns are frequently-used ethnomathematical activities in classrooms that have Native students (cf., Bradley, 1993). An example related to Navajo culture can be found in Addison-Wesley's book, *Multiculturalism in Mathematics, Science, and Technology: Readings and Activities* (1993). In the lesson, titled "Spider Woman Weaves a Rug," students read background information on Navajo weaving and answer questions about weavers' practices (including questions for critical thinking about mathematical principles involved). Next, they use colored pens and paper to design a rug, following instructions that will produce particular geometric patterns. Instructions read: "In the following activity you will make your own burntwater design. Begin with an 18" by 24" sheet of paper or newsprint" (p. 129). Explicit directions for folding paper and using cardboard "steps" to create a pattern follow, e.g., "Make a vertical fold to divide your paper in half. With the paper folded, make a horizontal fold to divide the paper in half again. Open the folded paper and lay it flat on the table. Use a blue pen or marker to draw your vertical and horizontal axes by tracing the fold lines" (p . 129). Symmetry and number patterns are explored in follow-up questions.

Compare this to a somewhat similar activity (intended as a mathematics assessment task), "Designing and Weaving a Rug," developed by fifth grade teachers in the Chinle Public Schools on the Navajo Reservation in northeast Arizona (Koelsch, 1994). (See Figure 3 on the following page.) This exercise also requires students to design a Navajo rug; however, because it was devised for Chinle students by Chinle teachers, it has a more personal character.

The striking feature of the Chinle activity is its strong reflection of local context, something which could be expected to make the task more relevant and more inviting or motivating. As research cited earlier suggests (cf., Lipka, 1991; Scollon & Scollon, 1983), the strong contextualization may allow students to "enter" the task more effectively, as they readily envision the situation presented.

Ordinarily, for example, this grandmother would probably not calculate formally how long she would need to weave the rugs. In keeping with phenomena noted by Sapir (1957) and Whorf (1956), our experience tells us that "time" can be construed quite differently in Native versus non-Native contexts. For instance, on one occasion one of us observed a tourist asking a traditional Navajo grandmother, "How long have you been a weaver?" At first the woman replied that she did not understand the question. However, after the

Figure 3
Designing and Weaving a Rug
Mathematics Assessment Task



Instructions:

You are spending the summer in the canyon with grandmother. In order to earn some money for new school clothes, grandmother has offered to weave a rug for you to sell, if you will create the design.

1. Design your rug in the grid on the following page.

2. Grandmother says it will take her five minutes to weave each row. How many minutes will it take her to weave your rug? Count the number of rows and multiply by five. Show your work below.

3. A tourist to the canyon came through on a jeep tour and stopped to watch grandmother weave. She was so impressed with grandmother's weaving that she asked grandmother to weave her a rug using her favorite pattern. Use the pattern below to design a rug. Use only this pattern in as many ways as you want. (*A simple pattern involving 4 squares is shown*).

4. Color in the tourist rug using two or three colors.

The Chinle rug task has three more parts that call on the student to make further calculations based on the number of colors used and grandmother's daily available time.

tourist persisted asking many more questions such as, "Maybe fifteen years, twenty years?" she finally replied, "I have always been a weaver." To this grandmother, and others socialized in traditional ways, the notion of using "time" to give boundaries to one's vocation can seem a puzzlement. But in the Western classroom there is a rationale for wanting to know the time required; such skills are useful beyond the traditions of one's community when viewed as part of a larger repertoire of mathematics and science abilities. Also both the child and the tourist might be anxious to know when their rugs would be ready. One can readily see the potential this activity provides for exploring such differences by combining cultural/ethnomathematical aspects with "school mathematics" procedures.

On another level, one that challenges values associated with the use of technology and mathematical and scientific information to bring about "progress," Chinle teachers have asked students to take on controversial and difficult environmental issues such as the mining of minerals on the reservation or the deforestation of Navajo lands. Without prescribing what students should think, instructional and assessment activities require students to use high-level language and literacy skills to develop their own understanding of complex scientific, social, economic, political and cultural issues entailed in making decisions that will affect the environment and their own communities' financial status. Table 2 shows an abbreviated version of the "Deforestation Task," a series of integrated activities that merge instruction and assessment. The task is a lengthy one: students collect information from many kinds of sources on a subtopic that interests them. They do library research, interview tribal members (including elders), prepare a written report, and — if they wish — design a presentation for either a live or video performance.

This activity has the potential to include ethnomathematical and ethnoscientific content, and it specifically addresses culture-based environmental content standards that teachers have drafted. Processes of inquiry, however, could be a hybrid of culture-based *and* school-based approaches. For example, interviewing elders about the background of deforestation and about their beliefs and values regarding the land would have to take a culturally-

Table 2
Summary of the Deforestation Task

Overview:

For this task, students will investigate deforestation in the local area. Through independent research, students will become "experts" in a particular aspect of deforestation. They will gather information from several sources, analyze their data, and participate in a presentation of their material and their conclusions.

The task will take five to eight weeks and will entail the following:

*conducting research,

*interviewing,

*preparing a presentation,

*giving a presentation,

*extension activities across the disciplines.

Instructions to students:

In this task you will collect data and information regarding one aspect of deforestation (such as erosion, endangered animals, economics, values, or effects on the bio-system and sacred places) to become an expert in one or more areas. You will conduct an interview about the issues and values of deforestation. You will work in small groups to present what you have learned in a variety of ways, including a debate in which you take a pro or con position on the topic of "deforestation."

Note:

The full task write-up specifies the kinds of skills, concepts, and processes that should be familiar to students in order for them to engage in the task, as well as kinds of resources students may want to use to complete the task. Sample extensions include literature studies, role-playing, drama, presentations to local governmental councils, field trips, and various writing activities.

Seeking Inclusion of Native Values in Mathematics and Science Instruction

accepted form. Students would likely have to translate the kind of data they gather into a form that fits the scientific inquiry approach of school. Still, by virtue of examining an issue that concerns their own community, students would not be learning mathematics and science in a decontextualized or objectivized form as is so often the case in the "Western" instructional model. A pedagogy of mathematics and science that would be in harmony with Native values is one that does not separate fact, value or principles and instruction from students' lived experiences.

Both the NCTM and draft Science standards stress the importance of linking new concepts to students' existing knowledge and experience base. If one scans the draft science standards (National Committee on Science Education Standards and Assessment, 1994), any treatment of the philosophy of science — which could situate the dominant paradigm within a universe of paradigms — is missing. And short of some mention of recognizing diversity (with the goal of ensuring that "all students participate fully in science learning" — i.e., the standard content and processes), there is little to suggest that positivistic science is anything but the only way to go. Within the teaching standards, there is one possible entry point for introducing multiple perspectives in the standards: Teachers of science are enjoined to develop communities of science learners in which all students are productive members and in which the habits of mind, attitudes, and values of science learning are fostered. To do this, teachers should:

- demand and display a respect for and value the ideas, experiences, and needs of all students, and
- give students a significant voice in decisions about the content and context of their work, and require students to take responsibility for their own learning and the learning of all members of the community.

However, shortly after this section one reads that teachers should:

- structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse, and
- model and emphasize the methods, attitudes, and habits of mind of scientific inquiry.

There does not seem to be any question as to what constitutes appropriate discourse or the habits of mind of scientific inquiry. However, one must ask, "Were this tested against a Navajo science curriculum and pedagogy, would there be overlap? Would there be conflict? Would any limitations in the mainstream approach be revealed?" In addition, the ongoing implication of the standards appears to be that the goal of teaching science is to produce more scientists, not more scientifically literate citizens (Madfes, 1994).

According to Benally (1988), even efforts that truly intend to recognize local beliefs and traditions remain essentially mainstream and are not consistent with Native realities. Benally explains that the Navajo focus is on preparing individuals to reach a state of *hozho* — the attainment of a balanced and harmonious life. All knowledge is viewed with respect to its ability to draw one closer to such a spirit of harmony. "Traditionally," he writes, "the individual is taught the interrelationship and interdependence of all things and how we must harmonize with them to maintain balance..." (p. 10). By contrast, "western organization of knowledge, with its fragmentation... and lack of connectedness, does not promote *hozho*" (p. 12).

Faculty from the Navajo Community College's Shiprock campus have developed a framework that serves to reorient mainstream Western teaching and curricular practices to an approach reflecting Navajo philosophy (Benally, 1988). Using the four directions as a cultural touchstone, they align their efforts to help students develop a balanced and harmonious life with four branches of knowledge: humanities and fine arts (knowledge associated with the east); professional and vocational knowledge (associated with the south); social sciences (knowledge associated with the west); and the natural sciences (knowledge associated with the north). As an example, a course in the natural sciences taught in accordance with this philosophy would demonstrate the interconnectedness and interdependence of all things. In other words, it would place that science within the broader context of life values and show its relevance to making a living and to one's social well being; it would consider issues of particular impact on the natural environment of various actions. Though space limitations prevent a more thorough treatment of the approach, the important point here is that the themes of knowledge and goals of learning woven throughout are fully integrated and reflect the Navajo world view. The Navajo approach also highlights other elements missing from the proposed standards, ones we identified earlier, i.e., the ethical and historical dimensions that place the scientific approach in a broader context — so that what is learned is an inquiring stance toward "science" itself. Perhaps content standards having to do with "science and society" are meant to address these dimensions; and at least theoretically, standards relating to "scientific inquiry" and "scientific explanations" could entail a philosophy of science orientation.

In discussing what would constitute a mathematical education for all, Bishop (1988) has said:

> It requires a fundamental awareness of the *values* which underlie mathematics and a recognition of the complexity of educating children about those values. It is not enough merely to teach them mathematics, we also need to educate them *about* mathematics, to educate them *through* mathematics, and to educate them *with* mathematics. Teaching children to do mathematics emphasizes knowledge as a "way of doing." A mathematical education seems to me, in contrast, to be essentially

concerned with "a way of knowing." That then speaks to me of a cultural perspective on mathematical knowledge (p. 3).

Pushing for Culturally Responsive Pedagogy

In keeping with Benally's observation noted earlier, the standards in *both* content areas currently lack social context. That is, they focus on the individual outside of culture, time, and history, rather than on the individual as part of a community — that of local cultural or worldwide scholarly community. They also assume that the individual scientist is the key to discovery, rather than recognizing that groups make discoveries, often independently in different communities. Finally, they fail to acknowledge the creative and aesthetic elements in scientific thinking and discovery — something we have not explored here but that needs to be addressed (Cook, 1994).

The new vision of a less hierarchically organized workforce composed of creative, flexible workers who routinely participate in problem-solving (Senge, 1990), is out of kilter with entrenched educational practices that continue to rank and sort students to produce a small percentage of highly successful graduates. A so-called "paradigm shift" would be required to effect most of the current educational reforms. From the point of view of the new paradigm, high performance is to be expected of all students, not just an elite few. Intelligence and school success are seen as dependent on experience — experience that must be more equitably accessible. In reality, much of the "new" vision is not new but has been proposed (by educational philosophers) and practiced in part by some educators in the United States for most of the twentieth century. However, what is different is the surge of interest in and cohesion around several goals associated with the "new" vision that can be seen in numerous simultaneous reform movements in the country today. At the heart of pedagogical reforms is a student focus that reflects a shift in emphasis from what is learned to the learning process itself and the critical role of the students in it. Entirely new roles and relationships are demanded for teachers, students, and communities. Also important is an increasing recognition of the situated and social nature of learning. There is no context-free knowledge to be doled out, as highlighted in the Ciulistet work that links pedagogy to the home communities of Yup'ik children and changes their role in learning.

Summarizing a number of studies including her own, Bartolomé suggests that successful pedagogies that are culturally responsive may have succeeded not solely because of cultural content and processes but because they humanize the classroom and equalize relations between students and teacher and among different social groups of students. According to Bartolomé (1994),

> Many of the research studies that examine culturally congruent and incongruent teaching approaches also inadvertently illustrate the equalization of previous asymmetrical power relations between teacher and students. Thus these studies, in essence, capture the successful negotiation of power relations, which

> resulted in higher student academic achievement and increased teacher effectiveness (p. 184-5).

Perhaps when students are given choices, when their own experiences and ways of knowing and communicating are reflected in the classroom, the most powerful result *is* in the changed relations that ensue. Students can become "equal partners in their own learning" (Bartolomé, 1994, p. 186). When students are truly respected and their knowledge is respected, they can learn even from highly academic instruction and less-than-perfect textbooks (Cook, 1994). A feature Bartolomé sees as the most promising is students' and teachers' joint negotiation of meaning in pursuit of a learning goal.

Teachers act as cultural mentors when they introduce students not only to the culture of the classroom, but to the cultures and discourses of particular subjects. In the process, they assist students in appropriating the skills (in an active fashion) for themselves, enabling students to behave as "insiders" in the particular subject or discipline (p. 188).

In contrast to teacher-centered instruction, this approach has elements of an apprenticeship model that can create mutual respect among members of different groups and between [majority] teachers and students from subordinated groups. Bartolomé (1994) goes on to say that

> [U]nless educational methods are situated in the students' cultural experiences, students will continue to show difficulty in mastering content that is not only alien to their reality, but is often antagonistic toward their culture and "lived experiences" (p. 191).

Other researchers, among them McDermott (1977), Nelson-Barber and Harrison (1994), as well as acclaimed math teacher Jaime Escalante showcased in the motion picture "Stand and Deliver," have shown a variety of methods to be effective when trust between teachers and students exists. In fact, Escalante asserts that even when students seem to be uninterested in education, it is the teacher who is responsible for giving students the desire to learn. He related the following in an interview: "My skills are really to motivate these kids, to make them learn, to give them *ganas* — the desire to do something — to make them believe they can learn... The teacher gives us the desire to learn, the desire to be somebody" (Meek, 1989). Dukepoo (1993a) relates the story of a teacher who emphasized "culture" by requiring students to count and categorize "beads, buckskins and bolo ties," but did little to arouse their interest in mathematics. Escalante and Dukepoo make a strong case for looking beyond superficially shared culture for explanations of success.

Final Observations and Recommendations

Still, such a point should not be embraced to the extent that we discount effective alternative pedagogical models such as that represented in the Kamehameha program in Hawaii, which has used Hawaiian communication styles in the classroom (cf., Au 1980). Though "specialized" instruction of this type could be dismissed as a validation of the deficit model rather than acknowledgment and incorporation of local perspectives, educators must begin to accept that the mainstream curriculum is "specialized" as well; it simply is not viewed this way by individuals whose belief systems match its own.

Today's teachers are being called upon not only to present modern mathematics and science in ways that emphasize concepts and meaning over skills, but also in ways that will actively engage our nation's increasingly diverse student body. For Native people who are sorely underrepresented in fields dependent on mathematics and science, there is a tremendous need for teachers who will enlist them to become explorers, who creatively develop their understanding, as well as for teachers who create connections among science, mathematics, technology and society. But most teachers simply do not have the background or experience to take on such tasks as the following: integrating math and science with other disciplines and with restructuring programs at the school site; replacing lectures and cookbook exercises with activities that enlist all students; providing resources and techniques such as heterogeneous cooperative grouping (understanding that what counts as "cooperation" is culturally defined); and serving as mentors to students as well as leaders of educational reform.

We believe that the success rate of Native students in mathematics and science programs will continue to increase as more attention is paid to the unique perspectives of these students and as the principles listed in Table 3 are used to guide their educational programs. (See also American Indian Science and Engineering Society, 1994.) Ultimately these principles can help to guide the improvement of mathematics and science instruction, and not just for Native groups. We caution that calls to "celebrate diversity" need to be backed up with understanding of the nature of that diversity and with the ability to provide multicultural education that fosters the inclusion of all students. Weak forms of multiculturalism risk trivializing diversity and attenuating open-ended explorations of diverse perspectives. As long as we are all celebrating superficial ethnic differences, there is no threat of examining the assumptions that maintain existing inequities and limit our vision. Alternatively, the society at large stands to benefit from gaining perspective on the ways in which values and practices based in mathematics, science, and technology affect human relations and the very earth itself. The issues go beyond empowering single groups to opening up greater possibilities for the whole society.

Table 3
Assumptions and Principles for Improving Pedagogy

- Educational standards and criteria for judging whether they have been met need to reflect greater participation of different cultural communities.
- Culturally-responsive education must go beyond "infusing" content into existing curricula; curricula need to be constructed that reflect the goals of local communities, and instruction needs to engage the participation of all students in high-level learning activity.
- All systems of knowledge are culturally situated. There is no such thing as pure mathematics and pure science. Therefore, a sociocultural perspective must be brought to the teaching of mathematics and science.
- Fundamental respect for the abilities of students, the value of the systems their communities have developed, and the potential perspective that can be brought to mainstream ways of knowing needs to be nurtured, supported, and demanded.
- All students come to school with mathematics and science knowledge, based on their own experiences within their communities, and this knowledge can be drawn upon to engage students in classroom learning.
- Western mathematics and science need to be regarded with greater perspective, that is within the contexts of their values, their histories, and the implications of their stances for the future of humanity and the planet. Alternative epistemologies should be explored, in part to lend perspective and for their own sake.
- Values associated with different epistemologies should be identified and explored. Teachers need to investigate ethnomathematical and ethnoscientific practices within their students' communities.
- Understanding multiple ways of knowing can be cognitively beneficial for all students, therefore teachers should provide opportunities for students to make their knowledge explicit and share it with each other.
- Important differences in ways of knowing and using language must be understood by teachers, if instruction is to improve for underserved students. Classrooms need to allow for different styles of learning, different ways of displaying learning, and different ways of participating in classroom activities.
- Native ways of teaching, e.g., serving as guide or facilitator, should serve as a model for constructivist teachers (reflecting a focus on acquisition vs. transmission of knowledge).
- Mainstream culture teachers need to look actively to non-mainstream culture teachers for examples of culturally-responsive practice and insights into interpreting performances of students from non-mainstream cultures.
- An instructional sequence that starts with real-world experience, moves to formal procedures, principles and abstracted concepts and back again to real-world context may be one way to link realms of theory, procedure, and practice and may be more developmentally appropriate for students.
- Students cannot be expected to make automatic connections among the different realms of theory and practice, so teachers need to help students see these connections.

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